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RAPID SEQUENCE INTUBATION OF THE PEDIATRIC PATIENT

Fundamentals of Practice

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Airway management is the first priority in the evaluation and care of pediatric patients in the emergency department. The goal is to ensure that ventilation and oxygenation meet the respiratory demands of these patients. Tracheal intubation is frequently the definitive component in optimal management of the airway. This skill requires a combination of knowledge, technical expertise, and sound clinical judgment to minimize the risk for adverse complications.

As the practice and specialty of emergency medicine have evolved over the past 20 years, the approach to definitive airway management has changed. Many emergency physicians consider rapid sequence induction of anesthesia to facilitate orotracheal intubation as the technique of choice.[59, 93, 110, 132, 133, 158, 164] At the same time, consultation with anesthsiologists has become increasingly uncommon, especially in hospitals with emergency medicine training programs.[37, 133] Conversely, anesthesiologists are more frequently involved in airway management of pediatric patients.[133] Community hospital emergency physicians share a similar discomfort with rapid sequence induction in pediatric patients.[168]

Rapid-sequence induction of anesthesia to facilitate orotracheal intubation has recently been differentiated from rapid sequence intubation (RSI) performed in the emergency department.[59] In reality, the names are interchangeable and the techniques identical with similar indications, goals, and risks. Consequently, adherence to basic common principles promotes the uniform standard of care essential to optimal outcome. Outcome is measured not only by successfully placing an endotracheal tube in the appropriate location but also by minimizing and managing complications associated with the two basic technical components of RSI: direct laryngoscopy and tracheal intubation (DLTI) and the induction of general anesthesia.

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RSI in emergency patients commits physicians to accept the potential for significant additional risk and must be balanced against the risks imposed by the ongoing severity of coexisting illness or injury. Emergency tracheal intubation of adult and pediatric critically ill patients outside of the operating room is associated with a frequency of complications ranging from 15% to 38%.[61, 132, 158, 165] Compared with adults, anesthetic respiratory complications in pediatric patients are significantly more common, especially in circumstances involving emergency surgery, younger age groups, a nonfasting state, and coexisting disease.[42, 77, 127] Despite the risk for complications, the relative safety and efficacy of RSI with respect to successful tracheal intubation have been documented.[37, 59, 61, 158] Before considering RSI, the overall risks and benefits must be carefully evaluated in every patient within the context of a comprehensive airway management plan (Fig. 1).

Tracheal intubation of adults and children in emergency departments is relatively uncommon, with an estimated frequency of 2 to 10 per 1000 visits.[61, 158]

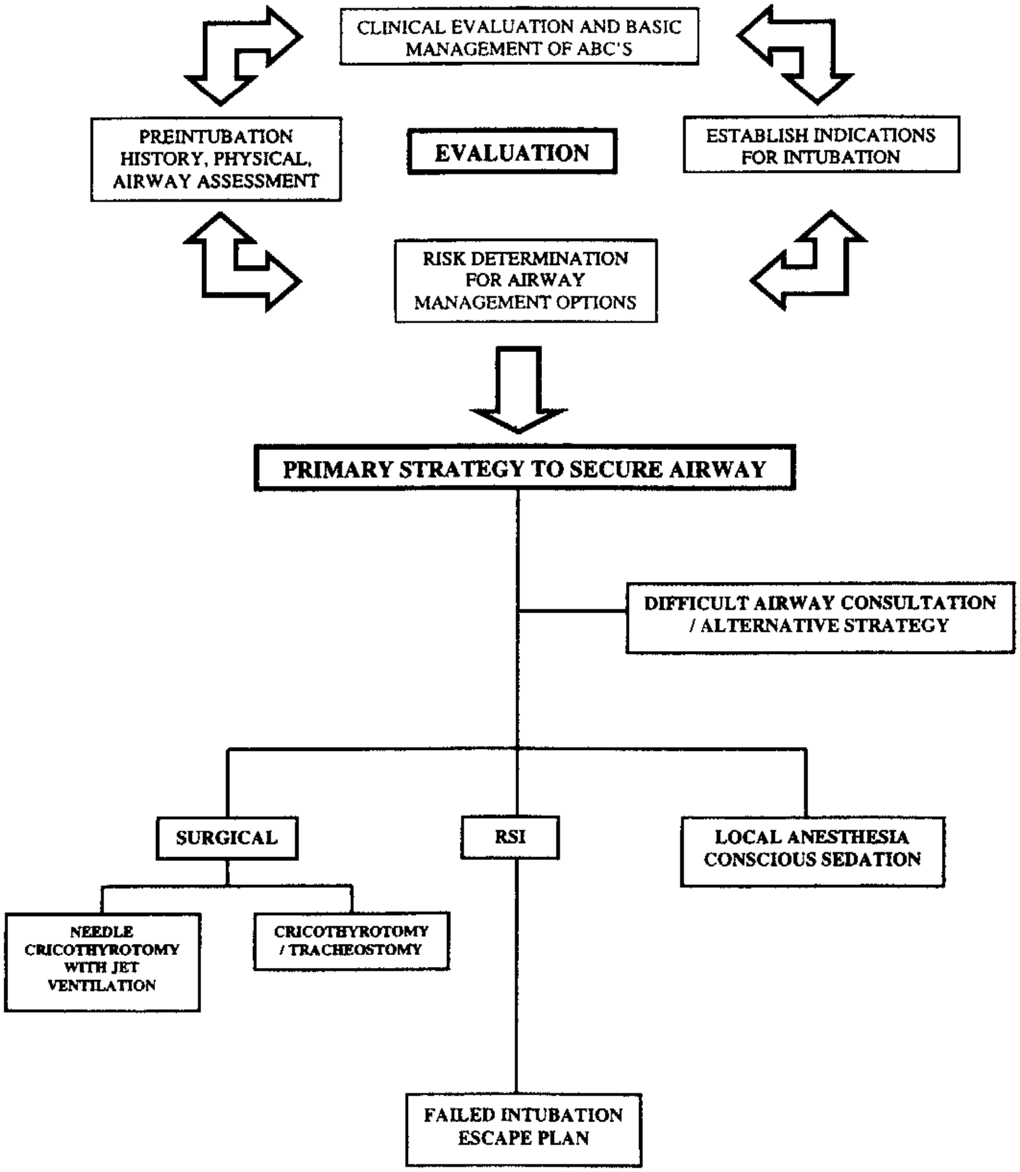

Figure 1. Airway management plan.

As with all such skills, training is required for both acquisition and maintenance of competence.[148] Recent work on intubation learning curves of trainees suggests that under ideal conditions in the operating room, a mean of 57 attempts is required for a 90% success rate.[97] Specific training in protocols governing anesthetic administration and RSI technique has been suggested to improve performance among emergency physicians.[37, 132, 148, 164, 209] RSI skills in the pediatric emergency department, similar to resuscitation skills in the operating room,[101] require periodic review to promote retention and maintenance of competence. The technique of RSI is a defined protocol that is modified by individual clinical considerations and implemented in a logical sequence. RSI has five components: (1) evaluation, (2) preparation, (3) intubation, (4) management of the intubated patient, and (5) a failed intubation algorithm (Fig. 2).

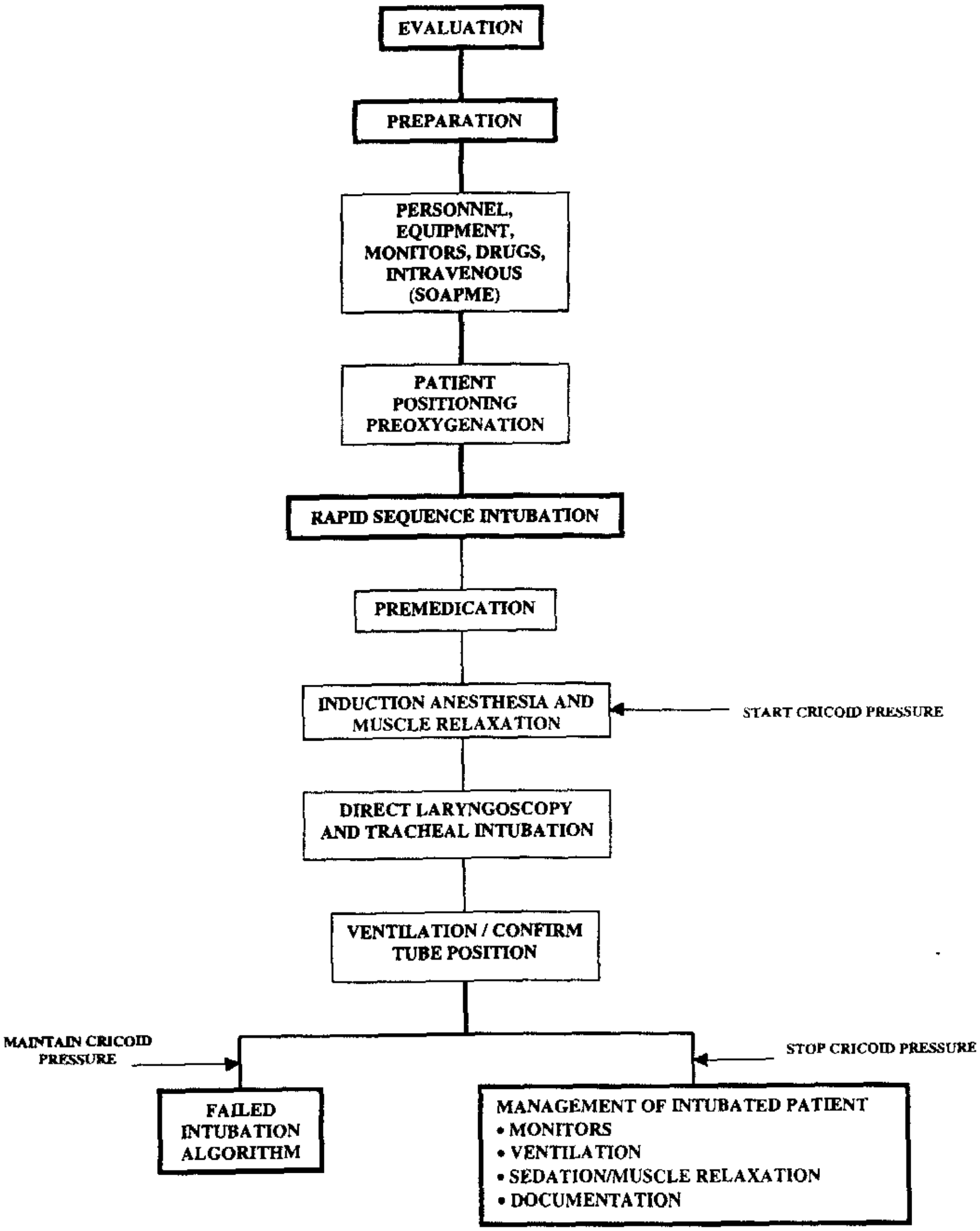

Figure 2. RSI protocol.

INDICATIONS FOR TRACHEAL INTUBATION AND RAPID-SEQUENCE INTUBATION

In general, the three basic indications for tracheal intubation of pediatric patients in the emergency department are:

1. Airway protection from aspiration or obstruction
2. Facilitation of positive pressure ventilation for the treatment of cardiovascular or respiratory failure
3. Optimal airway control and conditions for diagnostic or therapeutic interventions.

The indications for tracheal intubation are not necessarily the same indications for RSI. Moribund patients rarely require any medications to facilitate intubation, whereas most combative, head-injured patients require pharmacologic intervention. Establishing the indication for tracheal intubation is the first step in advanced airway management; selection of the appropriate intubation technique after careful medical evaluation is the second critical step in the evaluation process.

RSI is unique in emergency medicine because it requires the induction of general anesthesia. General anesthesia consists of four distinct pharmacologic components: (1) analgesia, (2) amnesia or unconsciousness, (3) muscle relaxation, and (4) blockade of pathophysiologic autonomic reflex responses to noxious stimuli.[174] No single intravenous agent is a complete anesthetic, and modern intravenous (IV) anesthesia frequently requires two or more agents to address all four components.[123] The state of anesthesia exists at one end of a continuum from conscious sedation through deep sedation and finally general anesthesia. Depth of anesthesia is also dynamic and is defined by examining specific clinical responses (i.e., movement or hypertension) to defined noxious stimuli (i.e., skin incision or laryngoscopy).

Rapid-sequence intubation is indicated in pediatric patients who require tracheal intubation but are considered at high risk for pulmonary aspiration of gastric contents ("full stomach"). The technique has three specific objectives:

1. Rapid induction of general anesthesia to attenuate autonomic reflex responses to DLTI
2. Rapid onset of optimal conditions to facilitate DLTI
3. Reduction of risk for pulmonary aspiration through cricoid pressure, minimizing the duration of time that the airway is unprotected (induction to confirmed tracheal intubation) and complete muscle relaxation to prevent vomiting

Relative or absolute contraindications include an anticipated difficult airway, inexperience or lack of training in the technique, and untreated shock.

The critical feature distinguishing the basic principles of RSI from those of safe anesthesia administration is the absence of drug titration to clinical effect. The rapid injection of preselected dosages of anesthetic and muscle-relaxant drugs is, at best, an estimate of the requirements for an appropriate depth of anesthesia. For safety reasons, RSI frequently sacrifices depth of anesthesia to achieve the primary goal of rapid airway control.[84] Both an anesthetic induction agent and muscle relaxant are essential to rapidly achieve ideal intubating conditions,[172] however the technique commits physicians to immediately assume responsibility for maintenance of the airway, respiratory and cardiovascular stability, and physiologic homeostasis. The unexpected difficult airway and adverse drug effects are the most serious risks of the RSI technique.

PULMONARY ASPIRATION

Perioperative pulmonary aspiration of gastric contents resulting in significant morbidity and mortality is a rare event in anesthesia. The overall incidence ranges between 1 and 10 per 10,000 anesthetics,[28, 83] but of patients that aspirate, significant morbidity occurs in 36% to 44%.[28, 199] The incidence of vomiting during emergent tracheal intubation outside of the operating room is estimated at 2% to 16%, with a 2% to 4% rate of aspiration.[61, 132, 165, 183] Most aspirations occur immediately before or during induction of anesthesia and tracheal intubation.[28, 199] The term *full stomach* allows for a wide variety of interpretations and is applied to patients with general or specific risk factors that are associated with an increased incidence of pulmonary aspiration. These risk factors include young infants, patients with recent oral intake, physical injury, pregnancy, gastroesophageal disease, recent narcotic use, increased severity of illness or injury, emergency surgery, obesity, head injury, or neurologic dysfunction associated with a depressed level of consciousness.[28, 47]

Most, if not all, emergency patients should be considered at increased risk for pulmonary aspiration. The available options to facilitate tracheal intubation in these patients and minimize the risk for aspiration are either awake or slightly sedated with local anesthesia, preserving both spontaneous ventilation and protective airway reflexes, or RSI. Selection of the most appropriate technique hinges on the airway and medical evaluation.

Various pharmacologic regimens are advocated to increase the pH and reduce the volume of gastric contents to minimize morbidity if aspiration occurs. These regimens include nonparticulate oral antacids, H_2 receptor antagonists, proton pump inhibitors, and gastroprokinetic agents.[182] Onset of action generally requires up to 1 hour, and their use should be considered if adequate time exists. H_2 receptor antagonists and gastroprokinetic agents, such as metoclopropamide, should be administered in these circumstances.

DIFFICULT AIRWAY AND TRACHEAL INTUBATION

Differences in the pediatric airway that can create difficulty with intubation have been reviewed.[48, 59, 134, 151] A difficult airway may be defined as difficulty with mask ventilation, tracheal intubation, or both.[36] The degree of difficulty in each patient varies on a spectrum from easy to very difficult and depends on the skill of the operator, various patient factors, and the clinical setting.[147]

Difficult mask ventilation is the failure to maintain previously acceptable hemoglobin oxygen saturation. Optimal mask ventilation requires some or all of the following techniques: anterior jaw thrust; effective mask seal; head and neck in "sniffing position", oral or nasopharyngeal airway; continuous positive airway pressure; and, most importantly, a second individual to assist in airway maintenance and ventilation.[116] Contrary to popular opinion, extension of an infant's head does not cause airway obstruction at the level of the trachea.[202] The inability to mask ventilate has considerably more severe consequences than does failure to intubate because subsequent airway management options are severely limited.[13]

Small subsets of patients (e.g., individuals with obstructive sleep apnea) are dependent on coordinated tone in the patency-maintaining muscles of the supraglottic airway (i.e., genioglossus muscle and others). They are very sensitive to small doses of sedation, anesthesia, and muscle relaxation and may

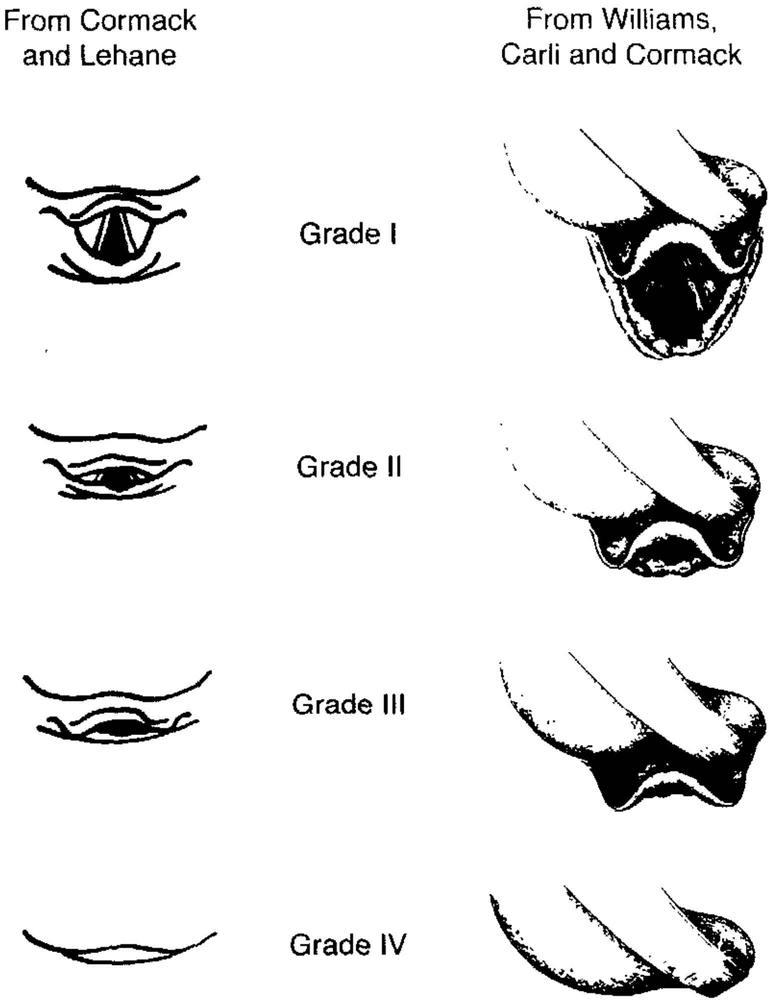

Figure 3. Four grades of laryngoscopic view. (*Adapted from* Benumof L (ed): Airway Management: Principles and Practice, St. Louis, Mosby, p 123, 1996; with permission.)

experience severe supraglottic airway obstruction at multiple levels. This can result in significant problems with mask ventilation and intubation.[200]

A difficult intubation has a variety of definitions, including the best view of the larynx on laryngoscopy, more than two attempts, requirement for an intubation aid or change of blades, and specific time limits.[50, 147, 158] The laryngoscopic view of the larynx can be graded according to a system developed by Cormack and Lehane.[46] This is a useful tool that correlates with intubation difficulty and facilitates communication of difficulty with assistants[46, 147] (Fig. 3). The consequences of a failure to intubate are less critical if mask ventilation is possible. Unfortunately, as many as 15% of difficult intubations are also associated with difficult mask ventilation.[204]

An optimal intubation attempt to achieve the best laryngoscopic view requires three essential components:

- The head and neck should be in the "sniffing position" to align the airway axes and facilitate a direct line of sight view of the larynx (Fig. 4).[11, 78] In adults, optimal flexion of the neck is 35° combined with 15° of head extension. This is accomplished by placing a small pillow behind the occiput or, in some obese patients, it may require extensive positioning.[52] Due to the cephalad position of the larynx and relatively large head,

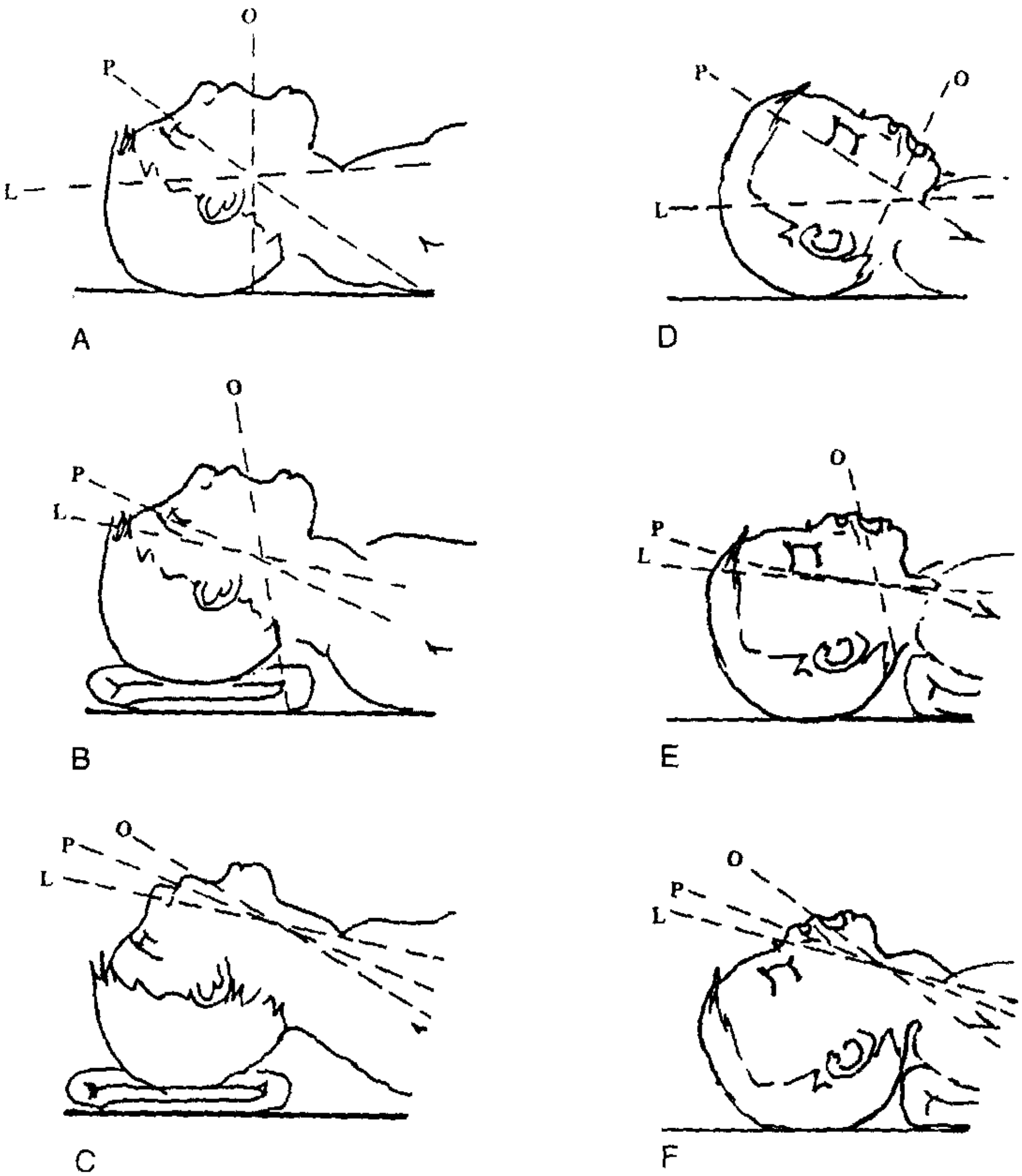

Figure 4. Positioning for tracheal intubation. Child 3 years of age or older. *A*, With patient flat on the bed, the oral (O), pharyngeal (P), and laryngeal (L) axes pass through three divergent planes. *B*, A folded towel placed under the occiput flexes the neck onto the chest and aligns the pharyngeal and laryngeal axes. *C*, Extension of the atlanto-occipital joint (into sniffing position) results in alignment of the three axes—oral, pharyngeal, and laryngeal. Child under 3 years of age. *D*, Large occiput causes hyperflexion of the neck on the chest and the oral (O), pharyngeal (P), and laryngeal (L) axes pass through three divergent planes. *E*, A folded towel may be placed under the shoulder (infants only) to reduce the hyperflexion of neck on the chest and align the pharyngeal and laryngeal axes. *F*, A slight extension of the atlanto-occipital joint (into sniffing position) results in alignment of the three axes—oral, pharyngeal, and laryngeal.

children under 3 years of age do not benefit from an occiput pillow but may require a small roll under the shoulders to maintain a neutral position.[49, 201]

- Optimal external laryngeal manipulation by the BURP (*b*ack *u*p and *r*ightward *p*ressure on the laryngeal cartilage) maneuver (Fig. 5C). Laryngoscopists should automatically perform this maneuver to improve visualization (often by a full grade) when the larynx appears "anterior."[92, 181] Excessive extension of the neck serves only to shift the larynx into a more "anterior" position.[205] This scenario is common when the potential displacement area in the floor of the mouth is poorly compliant or too small to accommodate the tongue and soft tissues shifted by the laryngoscope blade (Fig. 5*A* and *B*).
- Selection of an appropriate size and type of laryngoscope blade, skilled laryngoscopy technique, and direct elevation of the epiglottis, if necessary. Technique has been reviewed elsewhere.[11, 67]

The incidence of the difficult airway is not well defined and varies according to the definition used.[50, 154] A few conclusions have been made from the results of several large prospective series of adult patients intubated by anesthesiologists under operating room conditions.[13, 50, 153] Experience suggests similar statistics apply to the pediatric population[98]:

1. A poor grade 3 or 4 view of the larynx at laryngoscopy is common (2–16%)
2. Difficult tracheal intubations (> two attempts) are less common (2–4%); Four or more attempts may be required in 0.5% of patients
3. Failure to intubate the trachea is uncommon, with an incidence of 0.1% to 0.3%.
4. Inability to ventilate has a low incidence (0.02–0.001%).

Comparable large series of intubations outside of the operating room have not been published, but available data indicate an increased incidence of multiple intubation attempts (8–12%), which suggests a greater degree of airway difficulty.[61, 132, 158, 165] Prehospital intubations performed by emergency physicians are associated with significantly more difficulty than a comparable group of patients in the operating room.[2]

It is clear, particularly under the stress and less controlled conditions of RSI in emergency patients, that the first intubation attempt should be under conditions that optimize the success for both mask ventilation and direct laryngoscopy. The risk for difficulty is not insignificant, and each repeat attempt is associated with progressively increased morbidity and airway difficulty.[153]

Prediction of a Difficult Airway

The potential for a difficult airway may be self-evident because of preexisting or acquired conditions, however normal individual anatomic variation may also contribute to difficulty with either tracheal intubation or mask ventilation. Various physical characteristics are associated with difficult airways:

Small mouth, limited mouth opening, or short interincisor distance
Prominent upper central incisors with overriding maxilla
Short neck or limited neck mobility
Receding mandible or mandibular hypoplasia
High, arched and narrow palate

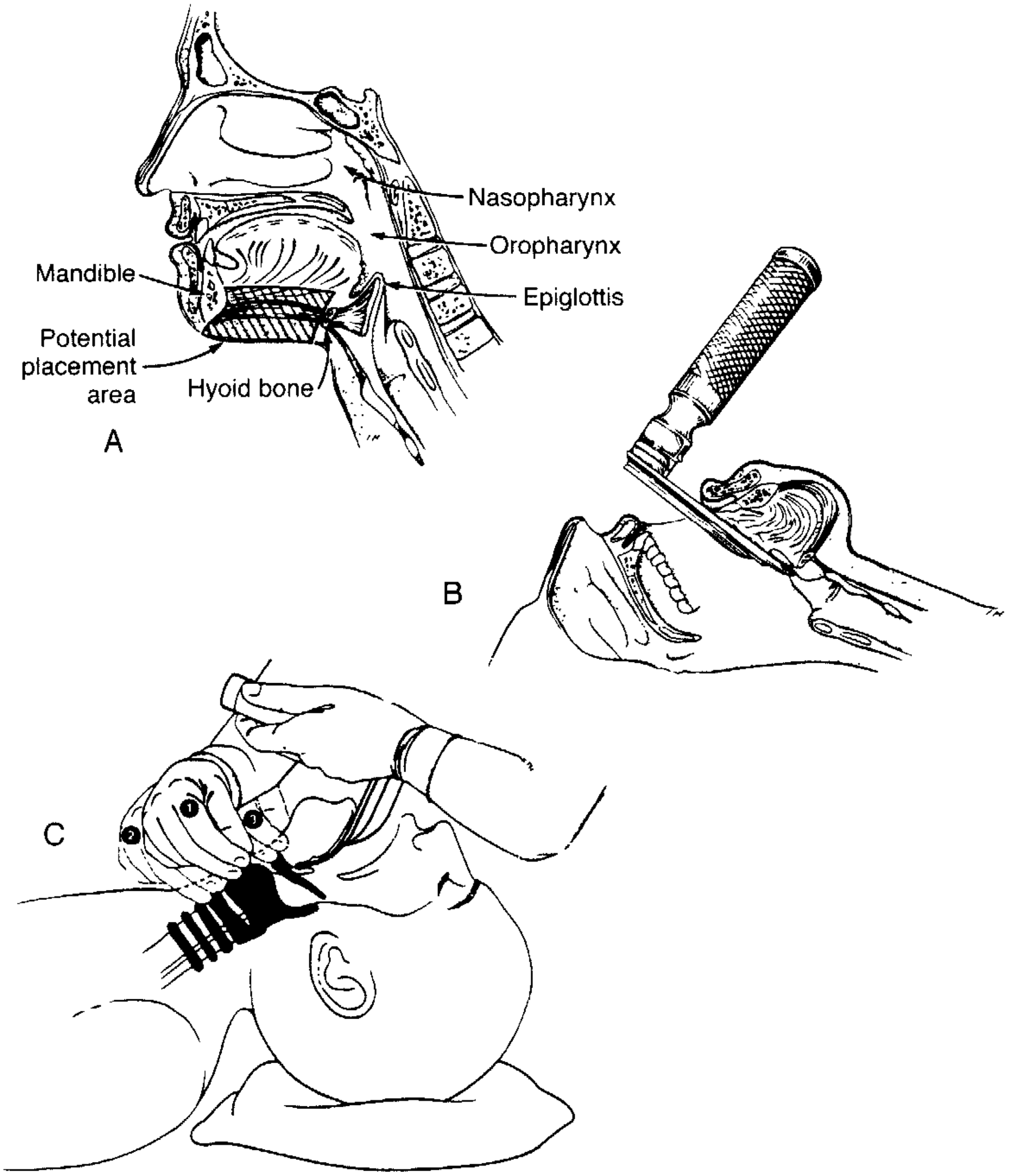

Figure 5. *A,* Diagram of airway, demonstrating *potential displacement area* for intubation. *B,* Laryngoscopy with displacement of the tongue and soft tissue into the *potential displacement area. C,* Burp maneuver, determining optimal external laryngeal manipulation with free (right) hand. (*A & B, Adapted from* Berry FA (ed): Anesthetic Management of Difficult and Routine Pediatric Patients. ed 2. London, Churchill Livingstone, 1990, p 173; with permission.) (*C, Adapted from* Benumof JL (ed): Airway Management: Principles and Practice. St. Louis, Mosby-Yearbook, Inc., 1996, p 268; with permission.)

Poor mandibular translation (temporomandibular joint [TMJ] dysfunction)
Rigid cervical spine
Obesity
Infants, particularly those with associated congenital anomalies

Morbidly obese patients and infants are particularly high risk.[42, 170] As a guide to airway evaluation, physicians should consider the steps required to visualize the larynx during laryngoscopy and the three fundamental problems that create difficult airways[135]:

Access—factors that limit access to the pharynx (i.e., trismus, large tongue, facial trauma, small mandible, morbid obesity, and C-collar)
Visualization—factors that restrict or prevent visualization of the larynx (i.e., reduced mandibular space, redundant soft tissue, airway secretions, and anterior appearing larynx)
Target—factors that physically distort or restrict intubation of the glottis (i.e., tumor, laryngeal displacement, subglottic stenosis, and extrinsic tracheal compression)

No single feature on physical examination accurately predicts a difficult intubation, but a variety of simple physical diagnostic tests have been suggested to identify these patients.[7] Most have poor interobserver reliability, high sensitivity, and low specificity that, combined with a low incidence, result in poor predictive value for a difficult intubation,[50] however an assessment strategy that combines the various tests improves the predictive value with respect to diagnosis of a difficult intubation. This comprehensive airway assessment reveals many but not all of the patients who will ultimately have difficult airways.[51, 205] A completely normal airway examination suggests a low probability for difficulty. The greatest value of this approach is recognition of the importance to thoroughly evaluate the airway before an intubation attempt.

None of the following simple diagnostic tests estimates the compliance of the submandibular soft tissue. In this regard, an "awake look" or a limited direct laryngoscopy with topical anesthesia and light sedation can provide valuable information.[7] In a similar fashion, indirect laryngoscopy has proven effective in predicting difficult intubation.[208]

Bedside Tests and Preintubation Airway Assessment

Mouth Opening

The interincisor distance, dental condition, TMJ function, degree of lymphoid hypertrophy, and presence of a high narrow palate are noted. The relative tongue–pharyngeal size is observed and can be classified according to the Mallampati/Samsoon classification (Fig. 6).[147, 162] A class of 3 or 4 indicates a relatively large tongue in relation to the pharynx, which suggests difficulty shifting soft tissues into the potential displacement area.

Mandibular Space

The thyromental distance is measured from the thyroid cartilage to the mental tubercle of the mandible with the neck in extension. It is best performed in the sitting position, if possible.[105, 117] Acceptable minimum measurements are 6 cm or three fingers in adolescents, 3 cm to 4 cm or two fingers in children,

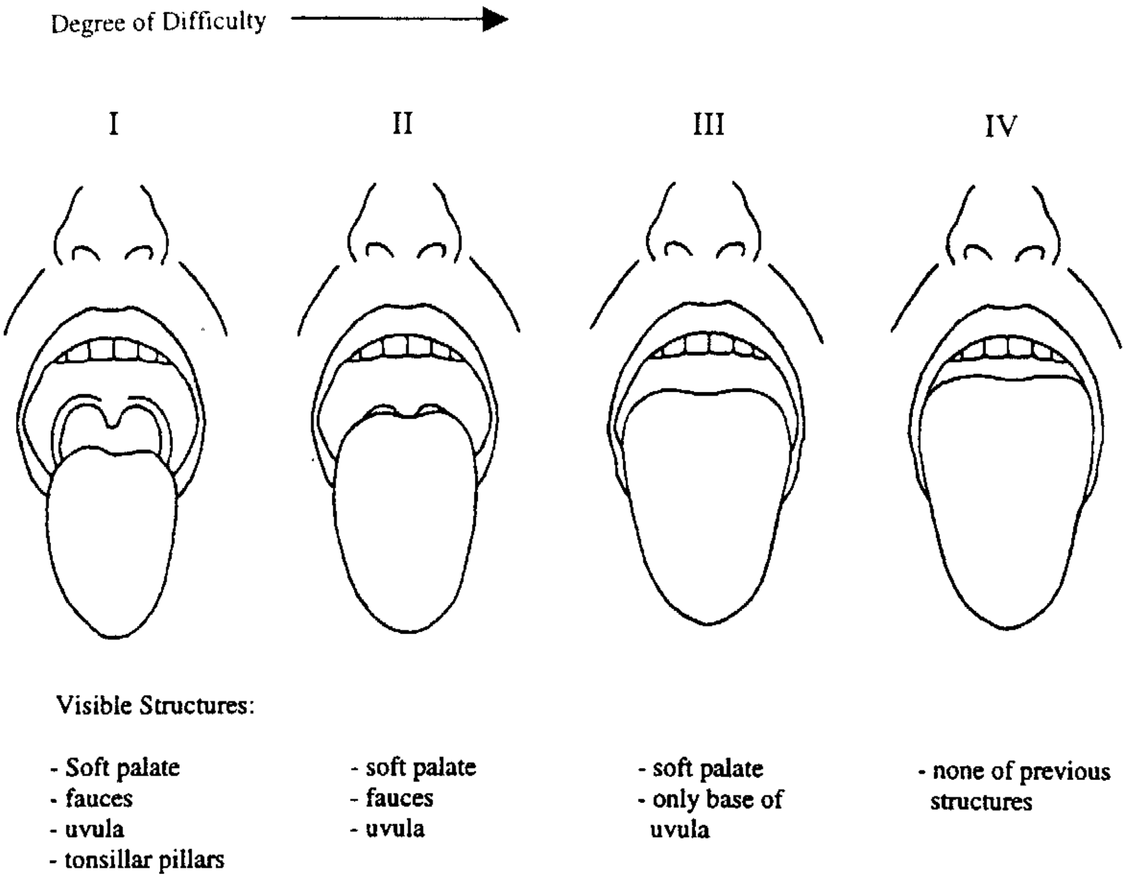

Figure 6. Samsoon and Young modification of the Mallampati airway classification. (*From* Benumof JL (ed): Airway Management: Principles and Practice. St. Louis, Mosby-Yearbook, Inc., 1996, p 132; with permission.)

and 1 cm to 2 cm or one finger in the infant.[48] The contour of the mandible must also be examined in profile. A small thyromental measurement combined with the appearance of a receding mandible as viewed from the lateral position suggests the mandibular space may not adequately accommodate the soft tissue displacement.

Atlanto-Occipital Joint Extension

The degree of extension is estimated by observing the sitting patient extend the head on the neck. An acceptable rotation from the horizontal is 35°.[205] Extrinsic restriction, such as by a C-collar, also results in limited joint extension.

An efficient and disciplined preintubation medical evaluation must be performed before RSI. This is arguably the most important step in the evaluation of these critically ill patients because the outcome of the examination and careful medical judgment determine the optimal airway management. A directed medical history can be guided by the mnemonic AMPLE (*a*llergy; *a*irway history; *m*edications; *p*ast medical, family, and anesthetic history; *l*ast oral intake; and recent *e*vents or history of present illness). The physical examination should focus on the airway, head, neck, and cardiorespiratory system. The overall objectives of the preintubation evaluation are threefold:

1. Estimate the potential risk for a difficult airway. A significant risk may dictate non-RSI alternative techniques or consultation as the primary approach.
2. Determine the impact of coexisting congenital or acquired disease or injury on the airway management technique.
3. Formulate a primary and alternative technique for securing the airway, including a specific plan for unanticipated difficulty with ventilation or intubation.

Alternatives to Rapid-Sequence Intubation and the Unexpected Difficult Intubation

Management of the anticipated difficult airway and full stomach has been reviewed.[26, 36, 186, 205] Use of topical anesthesia or conscious sedation with preservation of spontaneous ventilation and protective airway reflexes is the safest alternative technique to facilitate tracheal intubation.

Before RSI, a predetermined and specific plan should be ready for immediate implementation in the event of an unexpected failed intubation. An example is illustrated in Figure 7. The three stages in the algorithm are (1) determination of effective mask ventilation, (2) alternative approaches for optimizing intubation or ventilation technique, and (3) declaration of a life-threatening emergency. Failure to consciously activate the plan, recognize the need for help, and definitively move through each stage increases the risk for morbidity and mortality.[10]

Laryngeal Mask Airway and Failed Intubation

Several reviews are available on the laryngeal mask airway (LMA).[5, 12, 15, 25, 32, 187] A disposable LMA, unique, made of PVC, is now available and may be more cost-effective in emergency departments.[15] The primary indication for the LMA is the need for an intermediate airway in the setting of failed intubation or mask ventilation (Fig. 7). The Combitube is an acceptable alternative in older adolescents, but pediatric sizes are not available, and insertion is more complicated.[5, 21]

The LMA is important as both a supraglottic ventilatory device and as a conduit for tracheal intubation in the setting of an unexpected difficult airway (Fig. 8). It is not a replacement for the endotracheal tube and does not protect against pulmonary aspiration. The risk for gastroesophageal reflux may be increased with the LMA and general anesthesia.[5, 140] Cricoid pressure should be maintained during use of the LMA until the trachea is successfully intubated, however cricoid pressure may interfere with successful insertion and should be temporarily released to facilitate placement until the device is properly seated in the pharynx.[5, 32, 196] In addition, the success rate of fiberoptic or blind tracheal intubation through the LMA is significantly lowered by the simultaneous application of cricoid pressure.[32] The use of the size 1 LMA in infants and neonatal resuscitation may be more complicated than for older children.[117, 124, 143] The role of the LMA as an alternative to face mask ventilation during cardiopulmonary resuscitation (CPR) when personnel skilled in tracheal intubation are not available has been demonstrated.[15] Overall, it is a less secure airway, but benefits include ease of training, efficacy, speed of insertion, simplicity, and lack of dependence on direct visualization of laryngeal structures.[5, 15, 108]

Satisfactory placement and ventilation require the absence of protective airway reflexes caused by a patient's medical status, general or local anesthesia, or muscle relaxation.[5] A low-pressure seal with pharyngeal structures facilitates positive pressure ventilation.[31, 57] Minimal gastroesophageal insufflation of air

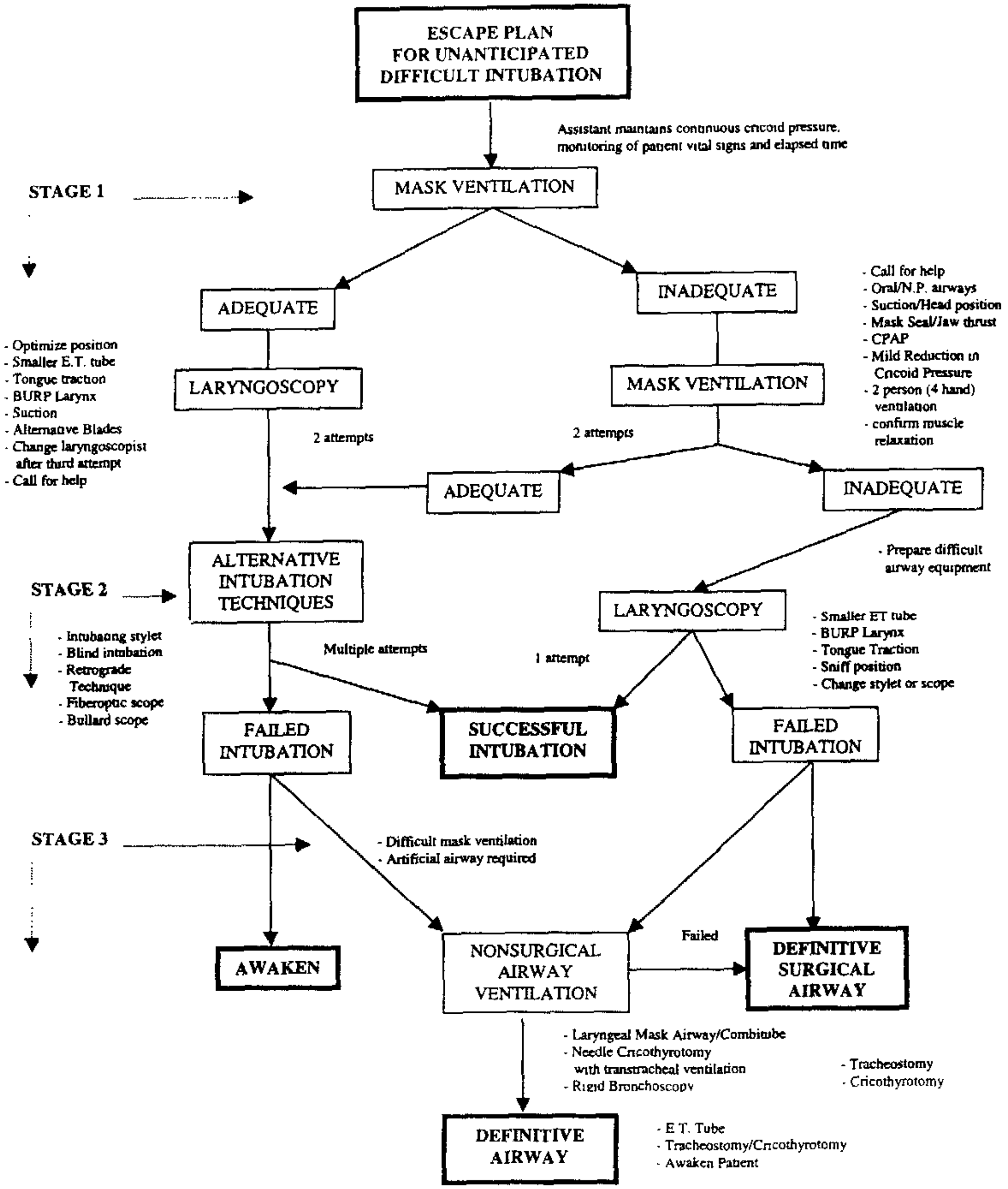

Figure 7. Failed intubation algorithm–escape plan for unanticipated difficult intubation.

occurs if pulmonary compliance and airway resistance are normal.[53, 57] Caution must be used to select the appropriate size of LMA based on the body weight of the child.[40] The adequacy of ventilation may be monitored by measuring end-tidal carbon dioxide, which correlates with arterial carbon dioxide in infants and children.[38, 39]

PHYSIOLOGIC CONSEQUENCES OF DIRECT LARYNGOSCOPY AND TRACHEAL INTUBATION

Attenuation or elimination of reflex responses to DLTI is a primary objective of RSI.[99] Afferent responses are initiated by the stimulation of the glossopharyn-

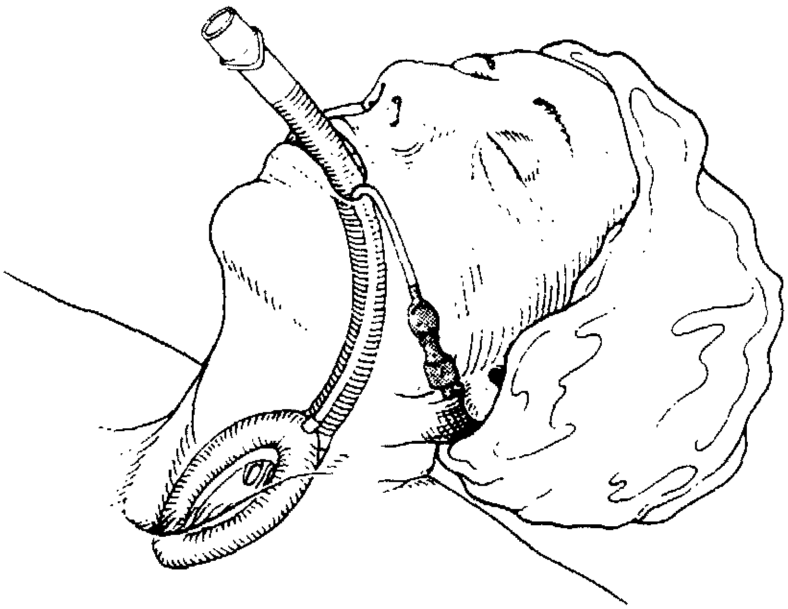

Figure 8. Laryngeal mask airway in anatomic position. When mask is inflated with the recommended volume of air (without the tube being held), the LMA may protrude slightly. (*From* Benumof JL (ed): Airway Management: Principles and Practice. St. Louis, Mosby-Yearbook, Inc, 1996, p 359; with permission.)

geal nerve above, and the vagus nerve below, the epiglottis. Reflex efferent responses to DLTI are generally short duration and of little consequence in most patients, but significant pathophysiologic effects can occur in some circumstances.

Protective airway reflex responses include apnea, gag, cough, sneeze, swallow, laryngospasm, and bronchospasm. Mechanical and other consequences of these reflexes are gastroesophageal reflux or vomiting, poor visualization of the larynx, airway obstruction, hypoxia, and hypercarbia. Some patients may experience negative pressure pulmonary edema caused by vigorous inspiratory efforts against a closed glottis.[104, 198] Severe intractable bronchospasm can occur with instrumentation of the airway, particularly with stimulation of the carina. An increase of as much as 140% in airway resistance is seen with healthy patients and can be reduced by prophylactic bronchodilator treatment.[66, 90] Active straining on an endotracheal tube may cause dramatic decreases in cardiac output or hypoxemia because of right-to-left shunting in young children with a probe patent foramen ovale ($\leq$ 34%).[126] Complete muscle relaxation and an adequate depth of anesthesia are essential to prevent these negative respiratory consequences of DLTI and achieve optimal intubating conditions.[85, 99, 172, 180]

Vascular effects of DLTI are mediated by the sympathetic and parasympathetic nervous systems. Parasympathetic responses with bradyarrhythmia are more common in children younger than 5 years than in older children. Significant hypertension and tachycardia associated with increased myocardial oxygen consumption occur as a result of sympathetic and adrenal medullary catecholamines.[85] The severity of hemodynamic alterations correlates with the duration of laryngoscopy.[176] Dramatic elevations in cerebral blood flow and intracranial pressure (ICP) can also occur.[24, 99] DLTI of awake infants causes up to 200% increases in ICP,[177] but hypercarbia, hypoxia, and motor responses to DLTI cause a significantly greater increase in ICP.[122, 177] Finally, DLTI increases intraocular pressure, but this is significantly less than the increase associated with other events, such as external pressure on the eye (as by a face mask) or obstruction of central venous return by a Valsalva maneuver.[51]

PREPARATION: EQUIPMENT, PHARMACOLOGY, AND MONITORS

Before RSI, all necessary monitors, equipment, personnel, and drugs must be assembled and organized. The ideal arrangement incorporates a mobile cart specifically designed for organization and storage of RSI and airway equipment. The mnemonic SOAPME is a useful memory aid for the five components of equipment preparation: (1) *s*uction, (2) *o*xygen, (3) *a*irway, (4) *p*harmacology, and (5) *m*onitoring *e*quipment.

Suction

At least one functioning wall suction with adult-sized Yankauer tips should be assembled at the head of the bed. Tracheal suction catheters of various sizes should be available (Table 1).

Oxygen

High-flow oxygen with a flow meter connected to a functioning bag-valve-mask device should be available. Adult bag-valve-mask devices are acceptable for pediatric patients.[188] Self-inflating bags require less training, experience, and technical facility than do anesthesia bags.[125] Use of a manometer to monitor airway pressures is less important than visualization of adequate chest excursion.[188]

Airway

A variety of size and age-appropriate transparent face masks with a cushion seal are essential. Mask fit is more important than resuscitation bag size for

Table 1. GUIDE FOR ENDOTRACHEAL TUBE SELECTION, LENGTH, AND SUCTION CATHETER SIZE

Age	Uncuffed (mm)	Cuffed (mm)	+ Length (cm)	Suction Cath (F)
1500–3000 g	3.0	—	7–9	5
Neonate–6 mo	3.5	—	10	6
6 mo–18 mo	4.0	3.0	11	6–8
18 mo–2 y	4.5	3.5	12	8
2+ y [8–10]	$^*4.5 + \frac{\text{age}}{4}$	$^*3.0 + \frac{\text{age}}{4}$	$12 + \frac{\text{age}}{2}$	10–12
Adult or equivalent	—	7–8.5	21–23	14

[*] Select endotracheal tube equal or closest to, without exceeding the estimated size.

[†] Length measured at maxillary gingiva or teeth. Alternative length formula, three times endotracheal tube size.

adequate ventilation.[188] Similarly, a variety of oral and nasopharyngeal airways and endotracheal tubes should be available. Because of the variability of pediatric airway anatomy, one size larger and smaller than the primary selection should be prepared in each case (Tables 1 and 2). The Guedel oral airway is commonly used. Selection of the appropriate size is important to avoid airway obstruction,[175] but it may be preferable to use the larger airway within a given range.[65]

Traditionally, uncuffed endotracheal tubes are recommended for children under the age of 10 years.[175] The limiting factor to endotracheal tube insertion in children is the funnel-shaped airway created by the narrow cricoid cartilage.[188] Cuffed endotracheal tubes have a larger outside diameter compared with uncuffed tubes of equal size, so children can tolerate larger uncuffed endotracheal tubes. Their use is recommended by pediatric anesthesiologists because of the lower resistance, improved airflow, and reduced incidence of mucosal injury causing postextubation croup, but cuffed tubes may be preferable in the emergency department because fewer repeat attempts are required to replace poorly fitting tubes, and the risk for aspiration may be less. A recent study documented the utility of this approach.[89]

A variety of formulas fairly accurately guide the selection of endotracheal tube size and depth of insertion. Age-based or length-based formulas may be preferable.[67, 89, 91, 109, 175] Confirmation of midtracheal location is empirically determined in all patients, but estimated size and depth should be calculated before laryngoscopy (Table 1). The endotracheal tube should be loaded with the appropriately sized malleable stylet, and Magill forceps should be accessible.[157] Proper use of the malleable stylet requires some training, but it provides vital directional control in cases of difficult intubation.

At least two functioning laryngoscopes should be assembled from a full selection of both straight (Miller) and curved (Macintosh) blades (Table 2). Generally, straight blades are preferable for children up to age 3 years, particularly the Wis-Hipple 1.5 for toddlers.[175] This straight blade preference is dictated by the cephalad position of laryngeal structures ("anterior larynx") for children up to approximately the age of 3 years and the relatively large head and tongue.[50, 188] Straight blades have a lower profile designed for direct elevation of the epiglottis and are preferred for visualization of the "anterior larynx." Personal preference generally guides laryngoscope selection after this age. The Oxyscope, a modified Miller blade, allows insufflation of oxygen and is useful in infants to prevent desaturation during awake intubation.[103]

Finally, a difficult-airway kit is an essential component of the RSI cart. The difficult-airway kit should contain familiar tools rather than a large number of items that may not have been used or practiced.[50] At a minimum, it should contain appropriate equipment for:

Table 2. GUIDE FOR ORAL AIRWAY AND COMMON LARYNGOSCOPE BLADE SIZE

Age	Oral Airway	Miller	Wis-Hipple	Macintosh
Premature	5.0	0	—	—
Neonate	5.5	0	—	—
6 mo–18 mo	6.0	1	—	—
2 y–6 y	6–7	—	1.5	2
6 y–10 y	7	2	—	2–3
11+ y	7–8	2–3	—	3–4
Adult or equivalent	8–9	3	—	4

1. An alternative to the face mask for failed supraglottic ventilation, such as the LMA or esophageal–tracheal Combitube (for older adolescents and adults only)
2. Equipment for an alternative approach to RSI in case of difficult laryngoscopy (Lightwand, Bullard laryngoscope, bougie, or topical anesthesia)
3. Transtracheal airway kit for subglottic ventilation in the event of a failed intubation and supraglottic ventilation (needle cricothyrotomy is most appropriate for children over age 5 years) with a mechanism to deliver oxygen under pressure

Pharmacology

Pharmacologic agents can be organized into three basic groups: (1) RSI, (2) resuscitation, and (3) postintubation sedation medications. The RSI group consists of an anesthetic induction agent and rapid onset muscle relaxant. Pediatric resuscitation medications should be readily accessible from a standard resuscitation cart. Agents for maintenance of sedation or anesthesia after intubation include narcotics, benzodiazepines, and an intermediate duration muscle relaxant.

In addition to the standard RSI technique of an IV general anesthetic agent and a muscle relaxant, premedication with a variety of pharmacologic agents before DLTI has been suggested to further attenuate adverse respiratory, cerebrovascular, cardiovascular, and intraocular effects.[99] The primary benefits of these agents are to add depth of anesthesia, modify succinylcholine side effects, or permit a reduced dose of induction agent,[66, 85, 99, 180] but premedication increases the risk for adverse drug reaction[43] and may distract from the primary purpose to rapidly control the airway. The relative risks and potential benefit of these adjuncts must be carefully evaluated in each case.

Intravenous lidocaine (1–1.5 mg/kg) or fentanyl (2 μg/kg) 3 to 5 minutes before induction is advocated by many authors.[43, 94, 99] Lidocaine is probably the safest alternative with regard to respiratory depression, but the benefit is controversial in children.[20, 99, 173] Topical lidocaine has been used to blunt adverse airway reflexes and may be as effective as IV lidocaine.[85, 99] Maximum doses of 5 mg/kg for aerosol delivery or 3 mg/kg in direct topical application minimize the risk for systemic toxicity.[99, 169] This technique, combined with conscious sedation, is preferable for the management of patients with anticipated difficult airways. Atropine (10 μg/kg) is recommended in infants for reducing the risk for arrhythmias or reflex bradycardia from laryngoscopy and succinylcholine; it is controversial and infrequently used in older children.[22, 114, 141, 167] Defasciculating dosages of nondepolarizing muscle relaxants are discussed with succinylcholine later in this article. In general, the authors believe that the speed and simplicity of a standard RSI technique outweigh the potential benefits of routine premedication for most intubations of pediatric patients in the emergency department.

Anesthetic Induction Agents

Rapid-sequence induction refers to the rapid, uninterrupted injection of preselected dosages of an induction agent and a muscle relaxant. The desirable characteristics of IV anesthetic induction agents in elective anesthesia frequently differ from the needs in the emergency department. In emergency departments, minor side effects can be tolerated if the agent is simple to store and administer; is potent; has a reliable and rapid onset of action; and has a high therapeutic index that maintains cardiovascular, cerebrovascular, and respiratory stability with few serious complications or drug interactions. Etomidate and Ketamine are currently the IV induction drugs that most closely fulfill these criteria, and all emergency physicians performing RSI should be thoroughly familiar with these two agents.

Etomidate. Etomidate has been available for approximately 30 years and was recently reviewed.[14] It is a potent induction agent, but unlike ketamine, it lacks analgesic properties. The drug is a solution available at a concentration of 2 mg/mL and is stable at room temperature with a long shelf life. It has been used extensively for induction, maintenance of anesthesia, and sedation, but experience in children is limited. The dose for induction of anesthesia varies from 0.2 to 0.4 mg/kg, with clinical recovery within 10 to 15 minutes.

Etomidate has mild respiratory-depressant properties when given alone but does not bronchodilate or preserve protective airway reflexes. Unlike other induction agents, etomidate does not stimulate or depress the cardiovascular system but instead minimally alters hemodynamics by maintaining sympathetic outflow and baroreceptor reflexes,[55] but because of a lack of analgesic effect, laryngoscopy may induce sympathetic stimulation and hypertension similar in appearance to ketamine.[58, 60] Small doses of fentanyl (1–2 μg/kg) attenuate this effect. Etomidate acutely decreases ICP but maintains hemodynamic stability, which is also unique among anesthetic agents.[14] The drug causes myoclonic activity such as coughing or hiccuping, which are not associated with electroencephalographic evidence of seizures. Focal electroencephalographic activity may increase in some patients with eleptogenic foci.[14] Intraocular pressure is reduced. It does not produce muscle relaxation but enhances the effects of muscle relaxants.[58] Etomidate is the drug of choice for rapid sequence induction in most pediatric patients in the emergency department as a result of these favorable characteristics.

The most significant problem with etomidate is a transient, reversible, dose-dependent inhibition of adrenocortical activity resulting in reduced cortisol production.[14] This effect may last 5 to 15 hours, but no evidence shows adverse clinical effects in patients after single-dose use.[14] Minor adverse effects, such as pain on injection or superficial phlebitis, postanesthetic nausea or vomiting, and myoclonus, are not an issue with RSI. No absolute contraindications exist for the use of etomidate, and relative contraindications include patients with known focal seizure disorders or adrenal insufficiency.

Ketamine. Several reviews of ketamine are available.[96, 149, 203] The agent has been available for more than 30 years and most closely approaches the "monoanesthetic" drug providing most components of anesthesia. It is a solution available at 10-, 50-, and 100-mg/mL concentrations and is stable at room temperature, with a long shelf life. Ketamine produces dose-related CNS depression characterized by profound amnesia and analgesia associated with open eyes, a slow nystagmic gaze, and electroencephalographic dissociation between the thalamocortical and limbic systems (dissociative anesthesia). These properties are different from any anesthetic induction agent and apparent at low doses.[29, 95] The dose for induction of anesthesia is 2 mg/kg, with clinical recovery within 10 to 15 minutes.

Ketamine is a mild respiratory depressant when given alone. It is the only induction agent with bronchodilator properties and a tendency to preserve protective airway reflexes, although aspiration has been reported.[149] The direct negative inotropic effects on the heart are overshadowed by dose-related sympathomimetic stimulation of the cardiovascular system. This latter effect coupled with profound analgesia are also unique characteristics of ketamine, but much of the analgesic benefit to attenuate adverse hemodynamic responses to noxious stimuli (e.g., laryngoscopy) is negated by sympathetic stimulation. Critically ill patients rarely respond with an unexpected decrease in pressure caused by the endogenous depletion of catecholamine stores.[203] The hemodynamic safety of ketamine in children with congenital heart disease has been demonstrated.[149] In general, ketamine is specifically indicated in patients with reactive airways or hemodynamic instability.

Ketamine is associated with several side effects. It is a cerebrovasodilator and historically was contraindicated in patients with increased ICP or intraocular pressure. These concerns have recently been questioned.[96, 149] Ketamine does not increase intraocular pressure.[6] The evidence for ketamine precipitating seizures is poor.[149] Ketamine tends to produce an increase in skeletal muscle tone but enhances the effects of muscle relaxants. It has no negative endocrine effects.[149] Hypersalivation and dysphoric psychotomimetic side effects are not usually issues during RSI. Ketamine is currently contraindicated in patients with elevated ICP and uncontrolled hypertension. Relative contraindications include thyrotoxicosis, hypertension, and major psychiatric disorders. The potentially deleterious effects on ICP or blood pressure and emergence reactions can be attenuated by benzodiazepines.[149, 185]

Muscle Relaxants

In normal neuromuscular transmission, the neurotransmitter acetylcholine is released from the nerve ending into the neuromuscular junction. Two molecules of acetylcholine are required at each nicotinic receptor for opening of sodium and potassium ion channels. After threshold potential of the motor endplate is reached, the muscle membrane is depolarized, and excitation-contraction coupling is initiated. Acetylcholine is rapidly metabolized by acetylcholinesterase located at the neuromuscular junction, and the muscle membrane repolarizes.

Neuromuscular-blocking drugs are divided into two general classes based on their mechanism of action at the neuromuscular junction: (1) depolarizing and (2) nondepolarizing agents. Both induce motor paralysis by preventing acetylcholine stimulation of nicotinic receptors located on the motor endplate, thereby interrupting neuromuscular transmission. Recent reviews of these agents are available.[27, 59, 68, 163] Succinylcholine and rocuronium are currently the most appropriate muscle relaxants for RSI because of their unique properties.

Succinylcholine. Succinylcholine is one of the few drugs that has maintained popularity for more than 45 years and is the only depolarizing agent clinically available. This popularity persists despite a long list of potential complications and minor side effects because it is the only agent with the fastest onset of action (< 1 min) and recovery (within 5–10 min). As a result, and unless specifically contraindicated, succinylcholine remains the drug of choice for RSI of pediatric patients in the emergency department.[59] Succinylcholine is available as a 20-mg/mL solution and loses potency after 1 month if stored at room temperature.

Succinylcholine or diacetyl-choline is, structurally, two linked molecules of acetylcholine. Succinylcholine binds to the nicotinic receptor, causing depolarization of the muscle membrane, fasciculation, and unresponsiveness to endogenous acetylcholine. Termination of effect is by diffusion away from the neuromuscular junction. The extremely brief duration of action is a result of rapid hydrolysis by plasma cholinesterase to inactive metabolites. Genetic abnormalities of this enzyme significantly prolong the duration of action in approximately 1 in 2000 to 3000 individuals.[27, 197]

The dosage of succinylcholine is 3 mg/kg in infants less than 1 year of age or 2 mg/kg in older children.[119, 120] Complete neuromuscular blockade occurs within 30 ± 7 seconds in 2- to 10-year-old children, with a 25% recovery time of 5 ± 2 minutes.[206] The dose requirement is increased by 50% if defasciculating dosages of nondepolarizing agents are used. The intramuscular (IM) dose is 4 mg/kg, but onset is delayed, and the duration of action is approximately 20 minutes.[64] Failure of the jaw muscles to relax (masseter muscle rigidity) may occur in 0.3% to 1.0% of pediatric patients[27, 64, 102, 138] possibly because of a variant of normal response or an inadequate dosage.[107, 120] Severe masseter muscle rigidity may be an early sign of malignant hyperthermia in a few patients.[138]

Side effects and complications are varied. Most are related to the depolarizing effects exerted through nicotinic receptors of the autonomic nervous system and muscle membrane. Complications, including the uncommon risk for precipitating malignant hyperthermia, have been reviewed.[27] The more important issues are discussed.

Arrhythmia. Transient increase in heart rate is common, but rare episodes of severe bradyarrhythmia occur secondary to vagal stimulation.[17] Bradycardia is less common following IV induction of anesthesia and significantly reduced by atropine. Infants are at greater risk than older children for bradycardia-induced hemodynamic compromise.

The most devastating arrhythmias are caused by dramatic hyperkalemia, which can lead to cardiac arrest. Depolarization of the muscle membrane causes fasciculation. Evidence of mild muscle injury can frequently be documented with transiently increased creatinine phosphokinase (CPK), myoglobin, and potassium.[23, 27, 118] Normally, the increase in potassium of up to 0.5 mEq/L is trivial.[118] The risk for exaggerated release of potassium is increased in certain *chronic* disease states or several days *after the acute phase* of selected injury, which then persists for several weeks. These high-risk conditions include large body surface area burns, multisystem trauma, traumatic spinal cord or other denervating injuries, extensive muscle necrosis, and selected chronic myopathies.[27] Reports of sudden hyperkalemia-induced cardiac arrest in children receiving succinylcholine have been associated with undiagnosed myopathies in young children.[155, 179] This prompted a warning by drug manufacturers[88] against the *elective* use of succinylcholine in young children, especially boys, under the age of 8 years because of the small potential risk for an undiagnosed myopathy.[155] Recognition of arrhythmias induced by pathologic hyperkalemia is essential for effective therapy of this uncommon complication.[27]

Increased Intracranial Pressure. Whether succinylcholine causes a clinically significant increase of ICP in patients with neurologic injury is controversial.[27] A recent review suggested that succinylcholine slightly increases ICP in lightly anesthetized patients, but the effects of DLTI, coughing, hypercarbia, or hypoxia vastly outweigh the effects of succinylcholine. The increase is significantly attenuated in neurologically injured patients and abolished by deep anesthesia, IV lidocaine, or a defasciculating dose of a nondepolarizing muscle relaxant.[100]

Increased Intraocular Pressure. The succinylcholine-induced increase in intraocular pressure is modest at most, starts at 1 minute, and lasts 5 to 7 minutes; it is significantly less than the increase caused by DLTI, coughing, or hypoxemia.[51, 211] Use of succinylcholine in the presence of an open-eye injury is controversial,[35] but no cases of intraocular contents expulsion have been reported,[51] and one large, retrospective study of open-eye injuries suggested the safety of succinylcholine.[106] An adequate depth of anesthesia with complete muscle relaxation and optimal airway control are usually more important than the theoretic concerns of succinylcholine aggravating open-eye injury.[27, 51, 76, 211]

Defasciculation. In general, fasciculations are less intense in children than in adults. The use of routine defasciculation doses of nondepolarizing muscle relaxants to attenuate the pathologic effects of succinylcholine on ICP and intraocular pressure in emergency patients is controversial and generally unnecessary.[35, 100] Problems with defasciculation include delayed onset of relaxation, elimination of a useful clinical sign to mark drug effect, symptomatic weakness in some patients because the drug must be given 2 or 3 minutes before succinylcholine, and potential distraction from performance of RSI. Maintenance of oxygenation and ventilation, adequate depth of anesthesia, and rapid airway control are greater priorities for most intubations in the emergency department.[27] If defasciculation is desired, rocuronium, 0.05 mg/kg, is the drug of choice.[72, 129]

Contraindications. Specific contraindications to the use of succinylcholine in RSI are easily identified in most situations, with the rare exception of undiagnosed myopathy or malignant hyperthermia. Contraindications include:

1. Malignant hyperthermia or associated conditions[27]
    - Central core disease
    - King-Denborough syndrome
    - Muscular dystrophy (Duchenne, Becker, myotonia, and others)
2. Chronic myopathy or denervating neuromuscular disease
3. 48–72 hours after acute phase denervating injuries, burns, or massive tissue injury
4. Pre-existing hyperkalemia (renal failure is not a contraindication)
5. Known plasma cholinesterase deficiency (risk for prolonged duration of action only)

Rocuronium. Rocuronium is a relatively new nondepolarizing muscle relaxant similar to vecuronium but with the fastest onset of action in the class. It acts by competitively blocking the interaction between acetylcholine and the nicotinic receptor. Rocuronium is the drug of choice for RSI if succinylcholine is contraindicated because of rapid onset, lack of active metabolites, paucity of side effects, and intermediate duration of action. Currently, mivacurium is the only available short-duration nondepolarizing muscle relaxant but is limited by side effects (histamine release), slow onset, and poor intubating conditions.[68] Rocuronium is available as a 10-mg/mL solution and loses potency after 60 days at room temperature.

Onset of complete neuromuscular blockade in children averages 33 seconds at a dose of 1.2 mg/kg and closely rivals succinylcholine,[111, 113, 206] but the time to 25% recovery (41 min) is eightfold more than that for succinylcholine, which classifies the drug as intermediate duration. No benefit is added with a "priming" technique.[206] A faster onset of action occurs in infants and children compared with adults, but the time to recovery in infants less than 10 months of age is up to twice as long as that of older children.[207] The major side effects after bolus administration are a transient 15% increase in heart rate that is of no clinical significance in children.[207] Rocuronium similar to succinylcholine, may be administered as an IM injection in the deltoid (1 mg/kg in infants, 1.8 mg/kg in older children) and achieve complete relaxation in 2.5 to 3.0 minutes, but clinical duration is more than 90 minutes.[150]

Nondepolarizing neuromuscular blockade induced by rocuronium may be completely antagonized by acetylcholinesterase inhibitors, such as edrophonium or neostigmine, and an anticholinergic agent (e.g., atropine or glycopyrrolate). These drugs increase the endogenous acetylcholine available at the nicotinic receptors of the neuromuscular junction and block cholinergic effects at muscarinic receptors of the autonomic nervous system, respectively. Complete antagonism requires 5 to 10 minutes but is reliably effective only in patients who have spontaneously recovered 25% of neuromuscular transmission (i.e., 30–40 min after administration).

Monitoring Equipment

All patients should be continuously monitored before, during, and after RSI. Twelve years ago, the American Society of Anesthesiologists adopted basic intraoperative monitoring standards, which were recently amended in 1996.[4] The standard states that oxygenation, ventilation, circulation, and temperature are to be evaluated "regularly and frequently in a steady rapid succession." Eichorn,[56] one of the original architects of the standard, emphasized the importance of vigilance and clinical judgment by stating, "Technology never 'prevents' anything. Behaviors can and do prevent intraoperative anesthesia accidents." Safety monitoring is no substitute for vigilance and good judgment, but is an early warning system for mishaps that may permit earlier intervention.

The Joint Committee on Accreditation of Health Care Organizations recognizes these concepts and stated in 1996 that sedations, which "may be reasonably expected to result in the loss of protective airway reflexes," are considered anesthesia care, and must follow the same standards as anesthesia care given in the operating room.[81] Support for harmonizing standards across specialties is illustrated in the 1992 revision of the American Academy of Pediatrics policy on monitoring pediatric patients during and after sedation for Diagnostic and Therapeutic Procedures[69] and in similar policies by other organizations.[3, 156, 171] The original policy in 1985[44] was prompted by multiple deaths of children given sedation in dental offices without adequate monitoring or management.[63] The critical point is the creation of a uniform level of care for all patients, independent of the location where the medical care is delivered.

The following basic physiologic monitors should be in place before induction of anesthesia and tracheal intubation in the emergency department:

1. Electrocardiography for rhythm and rate
2. Noninvasive blood pressure
3. Pulse oximetry for the assessment of blood oxygenation
4. End-tidal carbon dioxide analysis to confirm tracheal intubation and monitor pulmonary ventilation
5. Temperature monitoring as clinically indicated

Heightened vigilance, continuous monitoring, and attention to detail are necessary during the critical periods of RSI. Maximal physiologic instability and risk occur immediately after induction of anesthesia until successful completion of tracheal intubation and mechanical ventilation. Documentation of vital signs at least every 5 minutes is recommended.

The American College of Emergency Physicians differs on the requirement for carbon dioxide gas analysis as a monitor to confirm tracheal intubation.[144] The lack of objective outcomes research evidence supporting the use of carbon dioxide or other technological monitoring has been recognized.[34] Routine clinical assessment confirms tracheal intubation and adequate ventilation in most patients, but it has proven unreliable with disastrous consequences in many case reports, particularly those involving difficult airway management.[127, 159]

PATIENT PREPARATION: PREOXYGENATION, VENTILATION, AND POSITIONING

All patients who receive muscle relaxants before intubation incur a variable period of apnea. The time to desaturation depends on the oxygen content of the functional residual capacity and oxygen consumption. Functional residual capacity is the lung volume at the end of a normal tidal volume expiration when the recoil of the chest wall and lungs is balanced. It is an important buffer to minimize cyclic changes in Po_2 and Pco_2 between breaths. Functional residual capacity is relatively smaller in infants (25 mL/kg) and is 42 mL/kg in adults.[130] Functional residual capacity is further reduced by general anesthesia (15–20%), by the supine position, obesity, and various coexisting diseases.[136] Infants and children also rely on a variety of additional dynamic maneuvers to maintain their functional residual capacity. These include "laryngeal braking," chest wall muscle tone, and rapid respiratory rates.[30] The oxygen consumption of infants is 5 to 8 mL/kg/min and gradually decreases with age to adult levels of 2 to 3 mL/kg/min. Alveolar ventilation parallels this gradual decrease.[152]

The smaller functional residual capacity and loss of dynamic support under general anesthesia combined with increased oxygen consumption predispose apneic infants and children to more rapid hemoglobin desaturation compared with adults. Healthy infants and children 2 to 5 years of age desaturate (to 90%) within 25% or 42%, respectively, of the time duration in 11- to 18-year-old adolescents.[142] Most fully preoxygenated, healthy infants desaturate within 70 to 90 seconds.[54] Various other factors in emergency patients significantly erode the apneic oxygenation "window of safety," including obesity,[16] fever, respiratory disease, hypoventilation, gastric distention, and coexisting disease or injury.

Preanesthetic or preintubation oxygenation is a critical technique before instrumentation of the airway to increase the duration of time before the onset of hemoglobin desaturation to 90%. Ventilation with 100% oxygen before anesthetic induction "washes out" the nitrogen from the functional residual capacity and replaces that volume with oxygen (denitrogenation). Spontaneous or synchronous assisted ventilation with the patient in the optimal "sniffing position" is always preferred over controlled mask ventilation to avoid gastric distention. The recommended duration of preoxygenation varies between 2 and 5 minutes.[48] Four vital capacity breaths in adults achieved equivalent arterial oxygenation compared with spontaneous tidal volume ventilation for 3 minutes, but the time to desaturation was shorter.[62, 192] Recent pediatric data suggest that the minimum required duration is directly proportional to age, and that 100 seconds is adequate for most healthy children.[128] Denitrogenation is most effective with a tight sealing mask.[184]

Delay in functional recovery of spontaneous ventilation as a result of residual IV anesthetic and muscle relaxation limits the safety window of apneic oxygenation. This varies from 8 to 49 minutes for succinylcholine and Rocuronium, respectively.[206] Significant hemoglobin desaturation occurs before recovery of spontaneous ventilation if tracheal intubation or manual ventilation is not accomplished. These facts highlight two important features of standard RSI technique in seriously ill patients and young children: During the "wait time" (which varies directly with age) for onset of anesthesia and muscle relaxation before laryngoscopy and after the application of cricoid pressure, a tight mask seal should be maintained and one or two gentle manual ventilations administered to confirm the ability to mask ventilate; second, the duration of the intubation attempt should be carefully monitored as a guide to declaring a failed intubation. Failure to promptly intubate within a short time period after induction (30–45 s is reasonable for children), especially in the presence of known difficult mask ventilation, implies a need for rapidly activating a failed intubation algorithm (Fig. 7).[10]

Despite successful tracheal intubation and ventilation, the effects of anesthesia and positive pressure ventilation may significantly worsen gas exchange in some patients.[70, 136] The addition of positive end-expiratory pressure (PEEP), a vital capacity maneuver,[74, 135] or alteration of ventilation technique may reverse some of the negative effects and smooth the transition from wakefulness to controlled ventilation under anesthesia.

CRICOID PRESSURE

Cricoid pressure is the "linch pin" of RSI.[33] Sellick first studied the application of external pressure to the cricoid cartilage during inclusion of anesthesia in 1961.[166] Over the past 40 years, the "Sellick maneuver" has become widely accepted as a standard in the intubation of patients considered at risk for aspiration of gastric contents despite a lack of objective evidence supporting a beneficial outcome.[33] Relatively few studies have examined the technique in pediatric patients.[1, 131, 160, 161]

Recently, questions regarding the efficacy and safety of cricoid pressure have been raised.[80] Cricoid pressure may interfere with visualization of the larynx or mask ventilation[32, 193] and is frequently not applied correctly.[8, 79] The lower esophageal sphincter pressure is significantly reduced with 20 to 40 Newtons (5–10 lbs) of cricoid pressure in awake volunteers, thereby paradoxically increasing the risk for regurgitation.[189] Esophageal rupture may occur if the technique is applied in actively vomiting patients.[146] The use of cricoid pressure in the presence of laryngeal or cervical spine pathology and sharp upper esophageal foreign bodies is controversial.[33] Nevertheless, cricoid pressure is considered a standard of practice in RSI.

The cricoid cartilage is the only complete tracheal ring. It is shaped like a signet ring with the narrow portion anterior and the upper esophageal sphincter and cricopharyngeus muscle posterior. Cricoid pressure is a superficially simple and anatomically appropriate maneuver designed to obliterate the upper esophageal lumen and augment the normal sphincter. The procedure is designed to prevent both the passive regurgitation of gastric contents into the pharynx and gastric insufflation during positive pressure ventilation.

In adults, a force of 20 to 44 Newtons is applied in an anteroposterior direction directly against the cervical vertebrae, with the head maintained in the optimal "sniffing position" for tracheal intubation.[33] The 40-Newton force has been described as "firm" or the "pressure which would cause pain if applied to the bridge of the nose."[121] Specific training models promote acquisition and retention of the skill.[75] A force of only 20 Newtons should be applied in the awake patient to avoid triggering pain, airway obstruction, vomiting, coughing, or other protective airway reflexes.[33] Adult cadaver studies suggest that 20 Newtons do not contribute to rupture of the esophagus during retching.[195] Firm cricoid pressure prevented regurgitation at esophageal pressures of 75 mm Hg in infant cadavers.[161] This considerably exceeds intragastric pressures measured in actively vomiting patients.[33] Nasogastric tubes do not increase the risk for regurgitation[33] and may be left open to air, if desired.

Two modes of application may be used. Single-handed cricoid pressure usually involves the thumb and index or middle finger on either side of the cricoid cartilage to prevent lateral movement. The middle and index fingers may be applied directly over the cricoid cartilage in children, with the palm of the hand over the sternum to avoid interference with the laryngoscope blade. Double-handed cricoid pressure uses counter pressure, with the opposite hand supporting the neck and cervical spine. In either case, flexion of the head on the neck should be avoided to prevent increased difficulty with intubation. Double-handed cricoid pressure may be better than single-handed cricoid pressure in the presence of cervical spine pathology because it allows countersupport of the spine.[71] The technique permitting the optimal view of the larynx is controversial.[33, 193, 210]

The ideal timing of application during RSI is synchronous with the onset of unconsciousness and muscle relaxation to reduce the risk for esophageal rupture, but reduction in upper esophageal sphincter pressure induced by anesthesia commences before the loss of consciousness.[194] With these considerations, a force of 40 Newtons should be applied in unconscious patients or a reduced force of 20 Newtons applied immediately following the rapid sequence injection of a general anesthetic and muscle relaxant. This should be increased to 30 or 40 Newtons with the onset of unconsciousness and muscle relaxation.[33]

Gastric distention during mask ventilation increases the potential for regurgitation, impaired ventilation, and cardiovascular compromise.[131] In the absence of crocoid pressure, gastric insufflation is avoided if peak inspiratory pressures are kept below 16 cm of water, but considerable individual variation exists.[33, 131] Properly applied cricoid pressure prevents gastric insufflation at peak pressures of 25 cm to 40 cm of water in paralyzed and nonparalyzed infants and children with normal airway anatomy.[33, 131, 161]

The concept of "appropriate" cricoid pressure in pediatric patients is critical because the biggest problem with the technique is the potentially negative impact on airway management. The trachea of infants and young children are more easily compressed compared with those of adults, and improper positioning or force easily obstructs the airway. This results in complete airway obstruction during mask ventilation or significant distortion of pharyngeal and laryngeal anatomy, thereby creating difficulty with intubation.[131] The required pressure varies in these younger patients and may need to be empirically determined in each case based on the effectiveness of mask ventilation or visualization of the larynx. Cricoid pressure is not necessarily equivalent to optimal external laryngeal manipulation with the BURP maneuver[9] (see Fig. 5C).

CONFIRMATION OF TRACHEAL INTUBATION

Three critical questions must be rapidly and sequentially answered immediately after an intubation attempt:

1. Is the endotracheal tube in the trachea?
2. Is the tip of the endotracheal tube at the midtracheal location?
3. Can the lungs be ventilated?

The ideal test to confirm proper endotracheal tube placement should be quick, safe, simple, inexpensive, and reliable for all patient groups. Unfortunately, a perfect test does not exist. Usually, clinical evaluation is sufficient to answer these questions, but confusion can occur, especially in the setting of a difficult intubation. More sophisticated monitoring tools are necessary in these circumstances.

The importance of answering these questions is emphasized in recent reviews by the committee on professional liability of the American Society of Anesthesiologists. This committee monitors adverse anesthetic outcomes by examining closed claims files from US insurance carriers.[127] Adverse respiratory events are particularly common in children and comprise 30% to 43% of claims, with most related to inadequate ventilation, esophageal intubation, or difficult tracheal intubation. Many cases of esophageal intubation or inadequate ventilation highlight the unreliability of common clinical tests; 89% were considered preventable by improved monitoring (pulse oximetry and carbon dioxide gas monitoring) and were frequently associated with a difficult intubation. Similar data are available from the United Kingdom, Australia, and various case reports.[159] Data from patients outside of the operating room suggest a significant incidence of similar adverse events, with esophageal intubation occurring in 1% to 8% and difficult intubation (requiring more than two attempts) in 6% to 12% of patients in the emergency setting.[61, 86, 158, 165] Reviews on various techniques for confirmation of tracheal intubation are available.[19, 41, 159]

Direct visualization of the endotracheal tube passing through the larynx, fiberoptic visualization of the trachea after intubation, or observation of the tube between the cords are considered the gold standards for verification of tracheal intubation.[159] Two maneuvers facilitate direct inspection: (1) positioning of the endotracheal tube by the right corner of the mouth allows a better view of the larynx, and (2) before removing the laryngoscope, gentle posterior placement of the endotracheal tube in the direction of the soft palate improves exposure of the cords and allows confirmation of tube position.

Accidental extubation is avoided by carefully removing the laryngoscope, maintaining endotracheal tube position against the maxilla, with the fingers of the left hand and carefully taping at the appropriate depth. Neutral position of the head is important. Flexion and extension of the neck in children can move the endotracheal tube up to 2.5 cm toward the carina with flexion and away with extension.[178] The Trendelenburg position results in a shift of the endotracheal tube toward the carina, and lateral head movement causes the endotracheal tube to move away from the carina.[159]

The American Society of Anesthesiologists identifies monitoring of carbon dioxide (CO_2) in exhaled gas ($ETCO_2$) as a standard to verify tracheal location of the endotracheal tube (Standards for Basic Intraoperative Monitoring, 1996). Exhaled carbon dioxide confirms the tracheal location of the endotracheal tube in the presence of adequate pulmonary blood flow. Capnometry (measurement of CO_2), capnography (display of CO_2 waveform), and colorimetric detection of CO_2 are all valid methods for demonstrating CO_2 in exhaled gases. The measurement of CO_2 in exhaled gas correlates with $Paco_2$, which provides a second important monitoring benefit by objectively indicating the adequacy of pulmonary blood flow and ventilation. Each monitoring device is at risk for some error as a result of various equipment or patient problems. Patient problems are primarily related to an increase in alveolar dead space (e.g., low cardiac output, pulmonary artery obstruction, or cardiac arrest), endotracheal tube position in the hypopharynx, or CO_2-containing gas in the stomach. The efficacy of colorimetric devices has been confirmed in adults,[139] infants over 6 months,[87] and during pediatric cardiopulmonary resuscitation.[18]

More recently, various other methods have been developed to differentiate tracheal from esophageal intubation, including the esophageal detector device, the self-inflating bulb, the Beck Airway Airflow Monitor, and the syringe aspiration technique. These techniques are based on the anatomic differences between the esophageal and tracheal walls. They rely on the relative resistance of the trachea to collapse, compared with the esophagus, on application of negative pressure.[45, 73, 82, 137, 145, 159] These devices may fail to confirm tracheal intubation in infants (because of their compliant tracheas), morbidly obese patients, and in the presence of an obstructed endotracheal tube. Their major advantages are simplicity, speed, and reliable performance in the presence of cardiac arrest. They should be considered as a complement to, but not a replacement for, CO_2 monitoring.[112]

Auscultation for bilateral breath sounds in the midaxillary line and their absence in the epigastrium, combined with observation of symmetric chest movement and condensation of water vapor in the endotracheal tube, are important but unreliable clinical tests to confirm tracheal intubation.[159] This is particularly true in children because of easy transmission of esophageal "breath sounds."[191] The primary importance of auscultation is the verification of the midtracheal location of the endotracheal tube tip. Intentional endobronchial intubation has been used to determine the depth to the carina but risks the development of bronchospasm.[190] Chest radiography is a secondary confirmation of the clinical evaluation and assists with identification of other RSI complications.

SUMMARY

Rapid-sequence intubation and rapid sequence induction of general anesthesia are synonyms and refer to the technique of choice for tracheal intubation in many pediatric patients in the emergency department. The principles of safe practice and basic standards of care uniformly apply to all clinical situations in which the technique is performed. RSI has two basic technical components: induction of general anesthesia and direct laryngoscopy with tracheal intubation. The technique is a prescribed protocol that can be modified slightly by the clinical circumstances. RSI is designed to rapidly create ideal intubating conditions, attenuate pathophysiologic reflex responses to direct laryngoscopy and tracheal intubation, and reduce the risk for pulmonary aspiration. Optimal performance requires appropriate training and knowledge, technical skill, and sound medical judgment. Medical and airway evaluation, careful patient selection, recognition of the need for consultation or safer alternatives, thorough familiarity with appropriate drug management, and attention to detail are essential for minimizing the risk for adverse complications. RSI with a rapid injection of preselected dosages of an anesthetic induction agent and muscle relaxant is the pharmacologic technique of choice. Premedication should not be routinely used. Anticipation, recognition, and management of complications are inherent to the competent delivery of all medical care. The unanticipated difficult airway is arguably the most severe complication of RSI, and all individuals performing the technique must prepare in advance a specific plan for this scenario. As with all such skills or procedures, a quality assurance program is important to monitor care, and individuals practicing RSI need to take appropriate steps to maintain competence.

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